RADIATION DAMAGE TO ADVANCED PHOTON SOURCE UNDULATORS*

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Abstract

Radiation-induced magnetic field strength losses are seen in undulator permanent magnets in the two sectors with small-aperture (5 mm) vacuum chambers. Initially, simple retuning of the affected undulators could restore them to full operation. As the damage has accumulated, however, it has become necessary to disassemble the magnetic arrays and either replace magnet blocks or remagnetize and reinstall magnet blocks. Some of the damaged magnet blocks have been studied, and the demagnetization was found to be confined to a limited volume at the surface close to the electron beam. Models for the magnetic damage were calculated using RADIA and were adjusted to reproduce the measurements. Results suggest that a small volume at the surface has acquired a weak magnetization in the opposite direction. Simulations of the radiation environment at the undulators have been performed with the MARS15 code.

INTRODUCTION

Since radiation damage to undulator magnets is one of the major concerns of synchrotron radiation (SR) and free electron laser (FEL) facilities, many investigations of radiation effects on permanent magnets have been done under a variety of radiation conditions [1-5]. No conclusive results have been reached so far due to the many variables, such as type of radiation, radiation energy, type of materials, magnetic field environment, etc.

The Advanced Photon Source (APS) started top-up operation in 2001. Since then, there has been continuing degradation in the radiation intensity emitted from undulators in Sectors 3 and 4, where small-aperture vacuum chambers are installed. The degradation is due to a slight reduction of undulator magnetic field strength. In this paper, we present measurements of undulator radiation damage resulting from regular operations of the APS storage ring, and a simple modeling of the damage profile for an individual magnet.

RADIATION EFFECT IN UNDULATOR

Figure 1 shows examples of peak field degradation in the Sector-4 undulator during a run in 2004. The undulator is a hybrid permanent magnet undulator with a 33-mm period. Measurements of radiation doses were done by alanine dosimeters placed on the surface of magnets in the undulator. Magnetic field measurements at a gap of 11.5 mm were done with a Hall-probe measurement bench before and after each run. The difference curve in the bottom panel shows the damage increasing as one moves from the upstream end. The damage then peaks and decreases somewhat through the last part before the downstream end. The profiles of peak field degradation were very similar for other runs.

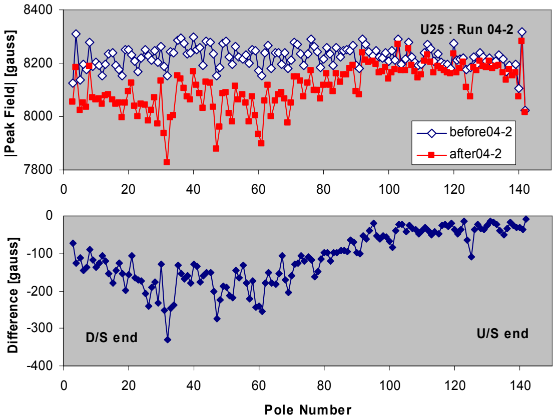

Fig. 1: Peak field comparison of the undulator before and after the May-August 2004 run. Bottom graph shows the difference before and after the run. Pole number is numbered from the downstream end. Open diamond: before user run, solid square: after user run.

Dose monitoring along the length of the undulator revealed significant dose non-uniformities. The doses are higher in the downstream (DS) end of the ID by almost an order of magnitude than the recorded doses in the upstream (US) end of the ID. The magnetic measurements shown in Fig. 1 also reveal that the radiation damage is higher in the DS end of the ID.

A dosimetry system would ideally exhibit radiation energy and radiation quality independent response in the radiation environment of interest. An additional requirement is a broad useful dose range. However, due to the mixed radiation environment around the storage ring in a synchrotron facility (that involves multiple radiation qualities and radiation energies and very broad dose ranges) this requirement can only be partially satisfied.

RADIATION EFFECT IN INDIVIDUAL MAGNET

In order to investigate the radiation damage in individual magnets, magnets were removed from the damaged undulator and were measured. Measurement was done by scanning a Hall probe near the faces of each magnet as

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shown in Fig. 2. Measurements were made both in the transverse (x) and vertical (y) directions.

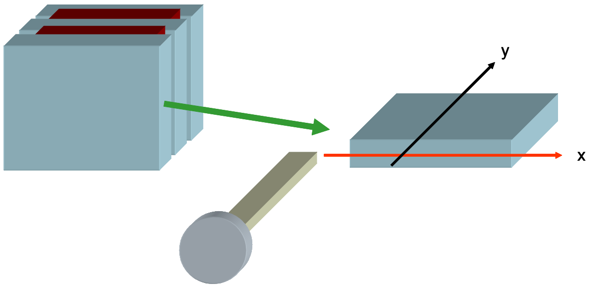

Fig. 2: Schematic of Hall probe measurement.

Figure 3 shows a comparison of measured magnetization profiles of a magnet extracted from a 27-mm-period undulator and profiles of model calculation. The magnet shown here was near the upstream end of the undulator. The undulator was installed in the upstream end of the Sector-3.

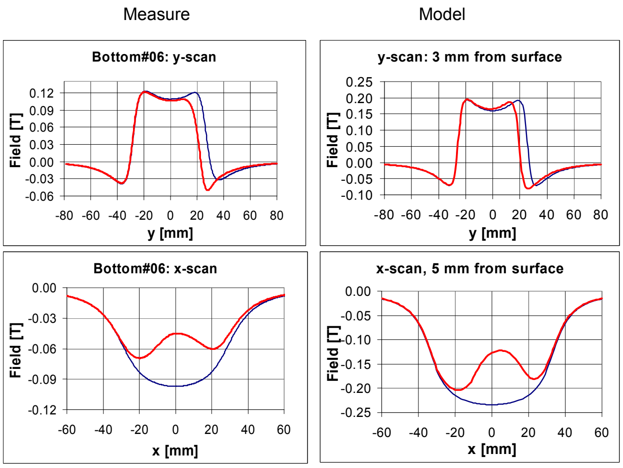

Fig. 3: Comparison of measurement and modeling. Thick red curves represent damaged magnetization profiles after irradiation. Thin blue curves represent profiles of the remagnetized magnet block. The magnetization levels of the two demagnetized regions in the model shown in Fig. 4 are -0.03T at the surface and 0.1T deeper in the magnet.

Simple modeling was done using the magnetic calculation code RADIA [6]. Measurements found that the demagnetized area was on the side closest to the beam, so the simple model shown in Fig. 4 was chosen. For simplicity, only two layers of damaged region were assumed. The thickness (in y) and width (in x) of each layer were assumed to be 3 mm and 25 mm, respectively. It was found that a gradual decrease in magnetization with depth into the magnet would introduce a different slope in the damaged curve at y≈ 20 mm, so a sharp edge to the demagnetization was necessary. Also, it was found that setting the magnetization of the surface layer of magnet to zero would not reproduce the dip in the damage profile seen at y≈ 25 mm. Instead, the magnetization at the surface had to be slightly negative. Apparently, the radiation has allowed the demagnetizing field the magnet is in to cause a slight remagnetization of that section of magnet in the opposite direction.

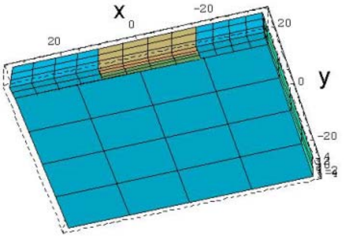

Fig. 4: Damaged magnet block model. The main part of the magnet has no demagnetization. In this simple model, there are two regions, each 3mm high and 25mm wide, near where the electron beam passes, that can have separate and different magnetization.

Simulations of the radiation dose to the undulator were carried out using the MARS code [7]. The model included the undulator magnets and poles, the vacuum chamber, and APS electron beam parameters. It was found that electron loss in the wall of the vacuum chamber induces electromagnetic showers coupled with photo-hadron production. The corresponding absorbed dose is highest near the beam axis, and may cause radiation damage to regions of undulator magnets nearest the beam. Figure 5 shows electron dose isocontours in the undulator.

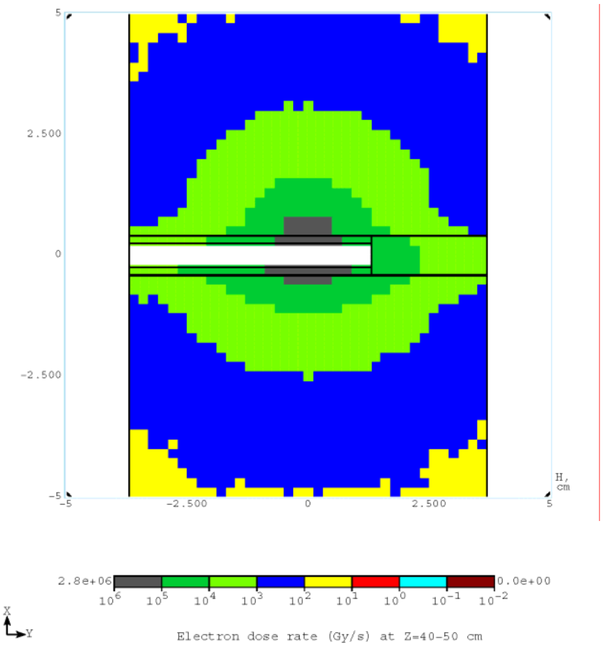

Fig. 5: Electron dose distribution in the undulator. 6.25×10^{14} e/s loss at 7 GeV was assumed for the simulation.

As can be clearly seen, the maximum dose rate is localized near the electron beam axis. Dose distributions from gamma-rays, charged hadrons, and muons all show very similar patterns. The neutron dose distribution, however, is rather broad, as shown in Fig. 6.

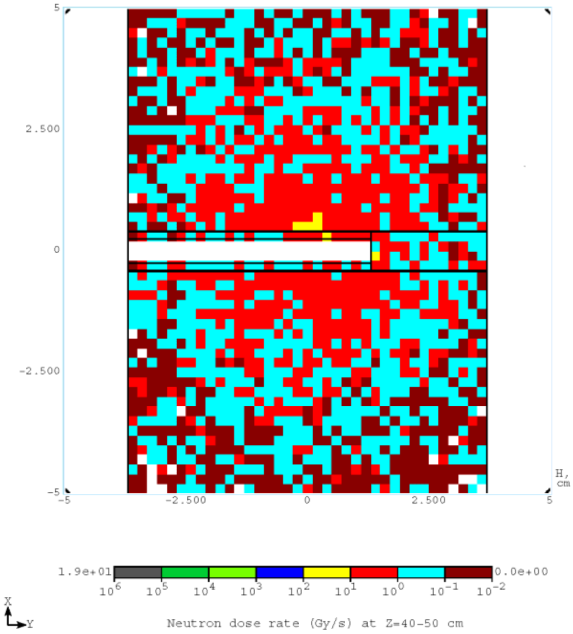

Fig. 6: Neutron dose distribution in the undulator. 6.25×10^{14} e/s loss at 7 GeV was assumed for the simulation.

Although it is too early for final conclusions about the cause of damage in magnets, the neutron dose appears to be too widely distributed to be primarily responsible for the localized damage observed experimentally.

CONCLUSION

Radiation damage to APS undulators was studied. The radiation damage is most significant at the ends of the straight sections with small-aperture vacuum chambers installed. Thus, since two devices are installed in those straight sections, the most damage is observed at the upstream end of the upstream device and the downstream end of the downstream device. Radiation damage to individual magnets is localized nearest the electron beam.

During the May 2005 maintenance period, the small-aperture vacuum chamber in Sector 3 is being replaced with a standard-aperture chamber, and new or refurbished undulators are being installed. We hope this chamber replacement will markedly reduce the radiation damage rate to these undulators. The other small-aperture sector, Sector 4, retains its small-aperture chamber, so we expect to continue observing radiation effects during upcoming runs. We have installed four sample magnets (2 NdFeB, 2 SmCo magnets) in a small radiation-test fixture located at the downstream end of the straight section for further investigation.

Radiation-induced demagnetization of magnets in insertion devices is one of the major concerns for SR and FEL community. In order to solve these problems, extensive and systematic studies are anticipated.

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